ULTRASTRUCTURAL REVELATION of the NATURE of PENNATION in the ABDOMINAL MUSCLES of CHILDREN with SPASTIC TYPE CEREBRAL PALSY (STCP): IMPLICATIONS for FORCE GENERATION

Article in Journal of Musculoskeletal Research · December 2018
DOI: 10.1142/S0218957718500082

CITATIONS 0
READS 27

4 authors, including:

Saviour Adjenti
University of Ghana
4 PUBLICATIONS 0 CITATIONS

Marianne Unger
Stellenbosch University
23 PUBLICATIONS 203 CITATIONS

Jennifer Jelsma
University of Cape Town
122 PUBLICATIONS 2,261 CITATIONS

Some of the authors of this publication are also working on these related projects:

ultrasonography of the postural muscles in children with spastic type cerebral palsy View project

Determination of the efficacy of rehabilitation villages as a service delivery model: A pragmatic quasi-experimental trial View project

All content following this page was uploaded by Marianne Unger on 10 April 2019.
The user has requested enhancement of the downloaded file.
ULTRASTRUCTURAL REVELATION OF THE NATURE OF PENNATION IN THE ABDOMINAL MUSCLES OF CHILDREN WITH SPASTIC TYPE CEREBRAL PALSY (STCP): IMPLICATIONS FOR FORCE GENERATION

Saviour Adjenti*,¶, Graham Louw†, Jennifer Jelsma‡ and Marianne Unger§

*Department of Anatomy, School of Biomedical & Allied Health Sciences
College of Health Sciences, University of Ghana
Korle-bu Campus, P. O. Box, KB 143, Korle-bu, Ghana
†Department of Human Biology, Faculty of Health Sciences
University of Cape Town, South Africa
‡Division of Physiotherapy, Faculty of Health Sciences
University of Cape Town, South Africa
§Department of Physiotherapy, Faculty of Health Sciences
Stellenbosch University, South Africa
¶saviour.adjenti@yahoo.com; ksdadjenti@ug.edu.gh

Received 26 July 2018
Accepted 13 November 2018
Published 10 December 2018

ABSTRACT

Purpose: To investigate whether the pennation angle (PA) in the abdominal muscles of individuals with spastic type cerebral palsy (STCP) has undergone any change when compared with those of typically developing (TD) individuals. To determine whether PA of abdominal muscles in individuals with STCP impacts differently on the force generating capacity, from those of TD peers. Materials & methods: Ultrasound images of the four abdominal muscles namely; rectus abdominis (RA), internal oblique (IO), external oblique (EO) and transversus abdominis (TrA), were obtained during the resting and active stages. ImageJ software package (version 2012) was used to measure the PA of the
sonographic images. Sixty-three individuals with STCP and eighty-two typically developing (TD) individuals took part in the study. The participants were between the ages of 7 and 16 years.

**Results:** The PA for three out of the four abdominal muscles was less than 3° while the RA muscle in both groups showed a pennation angle of zero degrees during the resting and active stages.

**Conclusion:** Excluding the rectus abdominis muscle, PA appeared to be altered in individuals with STCP when compared to their TD counterparts. The characterization of PA in abdominal muscles in both groups is, however, unclear. The PA as a muscle parameter may not be an important variable for differentiating the force generating capacity between individuals with STCP and their TD peers. Further investigation is required on MAP and the overall implication of each component on abdominal muscle function, especially in the maintenance of balance and posture.

**Keywords:** Pennation angle; Spastic type cerebral palsy; Abdominal muscles; Ultrasonography; Muscle architectural parameter.

**INTRODUCTION**

Muscle architecture primarily refers to the arrangement of muscle fibers in a muscle tissue. From the morphological and quantitative perspectives, the functional components that constitute the parenchyma of a skeletal muscle are collectively referred to as the muscle architectural parameter (MAP). These include: the physiological cross-sectional area (PCSA) which is also estimated to represent the muscle thickness (MT), at the greatest perpendicular distance of the fibers, pennation angle (PA) and muscle fiber length (FL). Each of these components of MAP has been linked to muscle function and the overall strength of a muscle. However, the most frequently inferred and implicated of this MAP regarding muscle function is PCSA or MT. There is evidence that muscle fibers in general, produce their greatest force at lengths slightly greater than their resting length (80–120%). Such reports are considered vital especially in the field of rehabilitation, for skeletal muscles which are known to possess remarkable plasticity. The ability of a skeletal muscle to quickly gain or lose contractile material according to changes in loading regimens (plasticity) coupled with the high capacitance for permanent disabilities in cases of individuals with spastic type cerebral palsy (STCP) partly accounts for the motivation for this collaborative empirical assessment of one of the components of MAP, the pennation angle.

The correlation between MT and function/strength has been widely documented in the limb muscles of healthy individuals and in those with skeletal muscle disorders. Similarly, FL is also variously implicated in muscle function, especially in the production of range of motion. The exact role of PA with respect to muscle function, especially in thin and flat muscles such as found in the anterior abdominal wall is unclear. A study on the thigh muscles of healthy adults, however, has shown that PA allows for more contractile materials per unit area than for non-pennated muscles. This evidence notwithstanding, little is known regarding PA in trunk muscles of either healthy individuals or those with STCP.

Generally, considering the arrangement of muscle fibers in a muscle tissue, skeletal muscles may be grouped into two basic types: pennate and non-pennate muscles. A non-pennate muscle is described as one in which the muscle fibers run parallel to the line of pull of the muscle, such that the fiber is in the direction of the overall muscle vector. On the other hand, a muscle with pennate arrangements is regarded as having muscle fibers which run diagonally with respect to the line of pull of the muscle. The angle...
formed between the line of pull and the alignment of the muscle fibers is referred to as the PA.\textsuperscript{1,5,22} It has been reported that the advantage of the pennate arrangement is the high force output due to the increased amount of contractile material per unit volume.\textsuperscript{5,28} Available evidence shows that although more force is produced by a pennate muscle, not all of this force is transmitted to the tendon.\textsuperscript{13,16,28} Similarly, the amount of force transmitted to the tendon for distribution, is shown to decrease with an increasing PA.\textsuperscript{3} The exact function of PA therefore, is unclear with respect to the overall function of a muscle. To quantify PA in a muscle or muscle group, especially in individuals with STCP may increase our understanding of the various components of MAP and in general muscle function.

Cerebral palsy (CP) is a condition that negatively impacts on motor function and postural muscle tone.\textsuperscript{25} It is acquired at an early age, with the STCP subtype being the most common.\textsuperscript{26} Children with STCP show mal-rotation of the trunk with an associated poor recruitment of the abdominal muscles.\textsuperscript{15,25} The general assumption among researchers in the field of musculoskeletal disorders is that, the ability to maintain upright posture may be lost in children with STCP.\textsuperscript{3} Therefore, a lack of torque for movement and optimum posture is often attributable to weak abdominal muscles, especially in individuals with STCP.\textsuperscript{27}

In relating theory to practice, a reduction in the mechanical properties, (extensibility and elasticity), of the gastrocnemius muscles of individual with STCP was reported.\textsuperscript{21,26} Such findings have practical implications for the management and rehabilitation options available for individuals with STCP. There is therefore, the need for further investigation of skeletal muscles at the ultrastructural level. Any rehabilitation regimen, either by means of physical therapy or chemotherapy, is meant to directly or indirectly improve on the contractile, extensible and elastic properties of skeletal muscles in individuals with STCP.\textsuperscript{9} From the anatomical and physiological point of view, these management options are aimed at enhancing those properties of a muscle needed for efficient generation of force.\textsuperscript{9,14}

No evidence however, exists on the extent of alterations, if any that a neuro-pathophysiological condition such as STCP is capable of having on the MAP of abdominal muscles at the ultrastructural level. Therefore, relating the success or failure of any management option to a specific component of MAP is anecdotal. Thus, in theory, a functional relationship may exist among the three components of MAP, yet the overall correlation of this relationship on the gross function of a muscle is unclear. In practice it is only MT and or the overall physiological cross-sectional area (PCSA) that has often been related to muscle strength and activity.\textsuperscript{5,28} Therefore, by inference the muscles of the anterior abdominal wall by their nature of being relatively thin have been categorized into a non-functional state. Furthermore, such a theoretical consideration fails to recognize the various types of muscles (pennate, non-pennate, thick and thin) that exist in the body.\textsuperscript{9,14,15} The gross appearance of the abdominal muscles, although may be regarded as thin compared to the limb musculature,\textsuperscript{9} no ultrastructural study is available on the MAP of these muscles, especially in individuals with STCP. Consequently, the individual action of each of the abdominal muscles, with regard to trunk stability is a subject of debate and an important area of research in the field of biokinetics.\textsuperscript{21}

With regard to biomechanics and human movement, adequate knowledge on the MAP, is important in the setting up of neuro-musculoskeletal models for the investigation of motion.\textsuperscript{21} According to Hodges and co-workers,\textsuperscript{14} as a result of the bipedal nature of human beings, any attempt to stabilize the spine (vertebral column) must be balanced by an optimal control from all
the components of the musculoskeletal system. Therefore, in order to provide a better theoretical basis for the planning of any rehabilitation intervention involving the optimal functioning of the abdominal muscles with regards to individuals with STCP, this study aims to:

- verify whether abdominal muscles in children with STCP undergo any pathophysiological transformation at the ultrastructural level, and
- determine whether these ultrastructural changes could impact any difference on one of the components of MAP, (PA) in terms of gross muscle function in comparison to those of TD individuals.

The ultimate aim of this study is to relate theoretical knowledge on musculoskeletal anatomy to clinical practice with respect to rehabilitation and the maintenance of pelvic stability in individuals with STCP.

An in vivo assessment, especially of the changes in muscle structure due to STCP has been the preferred technique with this type of ultrastructural investigation. In adherence to the guidelines for in vivo investigation on disorders of the human musculoskeletal system, our study involved the use of ultrasonography to measure one of the components of MAP, MT of the abdominal muscles. The other two parameters namely PA and FL were estimated with the aid of computer software packages (ImageJ). Ultrasonography was the preferred choice of this in vivo assessment because it is less expensive than other similar techniques, fast, reliable as well as devoid of any harm to both the participants and investigators.

METHODS

A descriptive, analytical and cross-sectional study design was used. Ethical approval was obtained from the Human Research Ethics Committee of the University of Cape Town (HREC REF: 490/2011). A SIEMENS® ACUSONIC X150 ultrasound imaging machine (Munich, Germany) was used to capture the thickness of the four abdominal muscles, Rectus Abdominis (RA), Internal Oblique (IO), External Oblique (EO) and Transversus Abdominis (TrA), both in the resting and contracted stages.

Participants

Sixty-three children (43.4%) with STCP and 82 (56.6%) typically developing (TD) individuals took part in the study. Participants from the STCP group were recruited from children attending special schools in Cape Town (convenient sampling method used). Children included in the TD group were learners from mainstream schools in the locality of the special-need schools. The mean age of all the participants was eleven years and three-months (Standard deviation (SD) = 3.0, range 7–16 years). Of the total sample, 53.8% were male and 46.2% were female.

Exclusion Criteria

Typically developing (TD group): A child who has undergone any surgical operation involving the anterior abdominal wall in the last six months prior to the commencement of the study.

The spastic type cerebral palsy (STCP) group: The Gross Motor Function Classification Scale (GMFCS) was utilized by a paediatric physiotherapist to determine the level of disability of the participants. Children at level V of the GMFCS scale (non-ambulatory) form part of the exclusion criteria because they were unable to perform the test maneuver. The second exclusion criterion is medical treatments that would have impacted on muscle function. For example, the use of botulinum toxin injection, casting, and surgical intervention such as dorsal rhizotomy and baclofen
pump placement in less than six months prior to the study.

**Procedure**

A SIEMENS® ACUSONIC X150 ultrasound imaging machine (Munich, Germany) was used to capture the thickness of the four abdominal muscles, rectus abdominis (RA), internal oblique (IO), external oblique (EO) and transverse abdominis (TrA), in both the resting and active stages. To test the muscles in the resting stage, children were asked to lie supine on the plinth with no activity. For the active stage, children were asked to lie supine on the plinth and then asked to perform the following activities: (i) To fully abduct the shoulder joint, (ii) to tuck in the chin and lift head and neck slightly towards the chest; and (iii) to flex the hip as far as possible. The performance of these activities was aimed at initiating a simultaneous contraction of the abdominal muscles, which was then measured. The average of these three maneuvers was recorded as the active stage thickness. The side of active upper or lower limb motion and of abdominal muscle thickness measurement was the affected side in hemiplegic children, the right side in diplegic, quadriplegic and TD children. The principal investigator handled the transducer head (ultra-sound probe) while one of the research assistants, a neurodevelopmental therapist, issued the instructions to the participants.

Using the umbilicus as a landmark the ultrasound probe was placed two to three centimeters from the midline and then was panned around in a semi-circular fashion until the bulk of the image from the deepest lying abdominal muscle, TrA, was observed on the image screen. This position was marked on the skin with a marker pen in order to ensure that the probe was kept in this position for subsequent measurements. The scanning head of the probe was then oriented along the mid-sagittal axis of each of the rest of the three anterolateral abdominal muscle (EO, IO and TrA) in a somewhat oblique fashion. The pressure of the transducer was kept to a minimum by using a generous amount of the contact gel in order to obtain optimum values for muscle thickness. All sites along a muscle from which images were taken at rest were then repeated during each child’s head and shoulder/leg lift movement (active stage). Images were stored on a personal computer and then analyzed with ImageJ Microsoft version 1.46, 2011 edition (Richmond, Virginia, USA).

Muscle thickness (MT) was determined using an electronic calliper on a frozen image. The length of a perpendicular line drawn between the echoes parallel to the fascicles from the deep up to the superficial aponeurosis (inter-fascial planes) was measured (Fig. 1). Since thickness varies along the length of a muscle, measurements were taken at three different points for a particular muscle according to the clarity of the image and the average was recorded for that individual.

Pennation angle (PA): The angle between the superficial and deep aponeuroses echoes were
defined as the pennation angle of each muscle (Figs. 1 and 2). Measurements of pennation angle and fascicle length and thickness were derived from computer stored images using ImageJ processor in Microsoft version 1.46. The major geometrical assumptions made in using such planimetric models of representing these sonographs of the muscles (thickness) as a two-dimensional figure (Fig. 2), especially in the determination of pennation angle were that:

- aponeuroses behaved as rigid bodies and run parallel to each other\(^ {12}\) and
- the fascicles ran straight between aponeuroses.\(^ {12}\)

The validity of the ultrasound equipment has been documented in the literature and found to be appropriate for use in research and diagnostic analyzes.\(^ {6-8}\) For the purpose of this study inter- and intra-tester analyses were carried out between the principal investigator and the research assistants on the same day and on different days on a cohort of the participants. The test-retest results all showed good to excellent correlations (ICC ratios > 0.70). Refer to Tables A.1-A.4 of Appendix A.

### Statistical Analysis

STATISTICA software package, version 11 (2012) was used to analyze the data. Due to the relatively large sample size, normality was assumed and parametric tests were used for all analyses. Independent \(t\)-test was used to statistically compare the means of the two groups in both resting and active stages. A two-way ANOVA with repeated measures was used to determine if there was a significant group-stage interaction that affected pennation angle. The changes in PA from rest to the active stage in each group were compared using paired \(t\)-test. A 95% confidence interval was used to determine the precision of the estimates of the differences in PA between the resting and active stages for both groups. Association between PA and age of all participants was assessed using the Pearson’s correlation coefficient. The level of significance for all statistical tests was set at 0.05.

### RESULTS

The mean PA for the two groups during the resting and active stages using a paired \(t\)-test are shown in Table 1. Results indicate that apart from the TrA, \((p = 0.058)\) statistically significant differences of the PA of the oblique muscles exist between the resting and active stages for individuals with STCP. Whereas for the TD group, the PA for the oblique and transverse abdominal muscles show statistically significant \((p < 0.001)\) differences between the resting and active stages using a paired \(t\)-test.

Figures 3 and 4 show the relative levels of PA among the EO, IO and TrA muscles during the resting stage between the two groups. The Pearson’s correlation graphs of the resting stage PA of the oblique and transverse abdominal muscles show statistically significant positive association \((p < 0.001)\) between the resting stage PA and age for both the STCP and TD groups.

Table 2 shows the result of the differences in the levels of PA between the two groups during the resting stage using unpaired \(t\)-test. Excluding
the PA of the rectus abdominis (RA) which could not be used in the analysis, (PA = 0.00 for RA in both groups during rest and activity) results show that statistically significant differences (p < 0.001) exist between the two groups with regard to PA during the resting stage.

Table 3 compares the means of PA during the active stages between the STCP and TD groups using unpaired t-test. The PA of the IO and TrA muscles show statistically significant differences between individuals with STCP and for those from the TD group. The PA of the EO muscles however, shows no statistically significant difference between the two groups (p = 0.083; t = 1.75).

**DISCUSSION**

In the light of some of these results, it could be inferred that PA may not be a significant indicator of muscle strength in the abdominal muscles. This inference is based on the relatively small degrees of PA as shown in our findings, coupled with the observation that the RA muscle in both groups showed PA of zero make it difficult to relate PA of the abdominal muscles to function or muscle strength. Regardless of the reasons behind these small measurements of PA, the main implication may be that the prediction used by Burtner *et al.* to estimate muscle mass, from which the PA is derived, may not be applicable to...
Table 2  Comparison of Means of Muscle Pennation Angle at Active Stage (Ac) Between STCP and TD Groups Using Unpaired t-test.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Pennation Angle/mm</th>
<th>Mean Difference</th>
<th>p-Value</th>
<th>95% CI of Difference/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>STCP (N = 63)</td>
<td>TD (N = 82)</td>
<td>STCP (N = 63)</td>
<td>TD (N = 82)</td>
<td>STCP (N = 63)</td>
</tr>
<tr>
<td>EO (t = 1.75)</td>
<td>1.83</td>
<td>0.23</td>
<td>1.90</td>
<td>0.25</td>
</tr>
<tr>
<td>IO (t = 2.95)</td>
<td>2.01</td>
<td>0.22</td>
<td>2.11</td>
<td>0.18</td>
</tr>
<tr>
<td>TrA (t = 3.70)</td>
<td>1.53</td>
<td>0.25</td>
<td>1.35</td>
<td>0.32</td>
</tr>
<tr>
<td>RA</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Note: All differences were significant at a p < 0.001 level.

Table 3  Comparison of Means of Muscle Pennation Angle at Rest (R) and at Active Stage (Ac) in Both STCP and TD Groups Using Paired t-test.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Pennation Angle (PA)/Degrees (°)</th>
<th>T-Statistic</th>
<th>p-Value</th>
<th>95% CI of Difference/(°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>Resting</td>
<td>Active</td>
<td>Mean Difference</td>
<td>Ac</td>
</tr>
<tr>
<td>EO</td>
<td>STCP</td>
<td>1.88</td>
<td>1.83</td>
<td>0.05</td>
</tr>
<tr>
<td>TD</td>
<td>1.62</td>
<td>1.90</td>
<td>−0.28</td>
<td>−10.56</td>
</tr>
<tr>
<td>IO</td>
<td>STCP</td>
<td>2.10</td>
<td>2.01</td>
<td>0.09</td>
</tr>
<tr>
<td>TD</td>
<td>1.93</td>
<td>2.11</td>
<td>−0.18</td>
<td>−14.99</td>
</tr>
<tr>
<td>TrA</td>
<td>STCP</td>
<td>1.58</td>
<td>1.53</td>
<td>0.05</td>
</tr>
<tr>
<td>TD</td>
<td>1.17</td>
<td>1.35</td>
<td>−0.18</td>
<td>−9.29</td>
</tr>
<tr>
<td>RA</td>
<td>STCP</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>TD</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Note: All differences were significant at p < 0.001.

the abdominal muscles. Results from our study showed that the RA muscle may comprise parallel muscle fibers with no evidence of any angulation of its fibers to the force of pull of the tendon/aponeurosis. This observation appears to have weakened any argument for the existence of a direct correlation between PA of the abdominal muscles, and the production of muscle force, especially in younger individuals, in contrast to that found in lower limb muscles.4,19 Although the present study was restricted to children and adolescents there were indications from our results to show that PA of the oblique and transverse abdominal muscles correlated positively with age of participants. This suggests that for the PA in the EO, IO and TrA muscles in both groups could be related to muscle function and strength during adulthood similar to muscle thickness, in a manner just as reported in the limb musculature.4,19

In the limb muscles, PA scores were reported to range from a minimum of 18° in the triceps brachii, to more than 20° in the vasti muscles and between 20° and 40° in the gastrocnemius.10-18,20 Based on these relatively large PA results in these studies, it is prudent to relate PA to muscle strength on account of these comparatively large PA in the limb musculature. From the current study PA of zero was recorded for the RA muscles in both the STCP and TD groups while in the oblique muscles as well as the transverse abdominal muscle PA of less than 3° was observed. It is tempting to hastily infer that the RA muscle in both groups is a weak muscle or incapable of...
generating muscle force on account of the results above. However, what the PA results for the RA muscle in both groups (Table 1) tend to highlight is probably that this parameter may not influence abdominal muscle function as the pennation angles remained unchanged during the resting and active states in both groups. The implication of such an inference would mean that physiologically, PA as a muscle parameter essentially may not differentiate abdominal muscle activity in individuals with STCP from those of their TD counterparts.

A study by Shortland and colleagues showed that the pennate arrangement in the lower limb musculature is directly proportional to muscle thickness. Consequently, muscle thickness and pennation angle as MAPs have been linked to high force output in these muscles. The amount of force generated by the muscle fibers in the lower limb was therefore, ascribed to the increased amount of contractile material per unit volume resulting from the large PA. This is the expectation, should the correlation that exists between muscle thickness and function, as reported in the lower limb muscles also be reflected in the abdominal muscles. In addition to muscle thickness, Kawakami et al. also showed that there is a positive association between muscle thickness and PA across individuals. Reports such as these formed the basis for the generalization that PA follows muscle thickness in predicting strength of skeletal muscles. There were no similar reports on thin or flat muscles such as occur on the anterior and anterolateral abdominal wall. All the reported positive correlation cases between muscle thickness and PA would need to be established first in the abdominal muscles and other flat/thin muscles, as observed in the limb muscles, before any consideration of regimen changes in rehabilitation of muscle disorders based on these facts and figures regarding any of the MAP. The lack of empirical evidence of a relationship between muscle thickness and PA of the abdominal muscles implies that discussions on this muscle parameter (PA) is based on the assumptions that what pertains in the lower limb muscles may generally be the case in the abdominal muscles as well.

The results in the present study (Table 1) showed that physiologically there are differences between the STCP and TD groups of the changes in PA from the resting to active stages. This change in PA indicates that a positive change could be seen in the TD group in which the functioning of abdominal muscles is regarded as being intact in contrast to the STCP group which showed negative or no changes in the case of the RA muscles. Based on the results above, our study surmised on account of the significant differences between the two groups of the changes in PA from the resting to active states, that PA may be an active parameter in determining muscle activity. However, given its characterization (present, absent, decreasing and increasing from resting to active stages), in the two groups makes this variable an unimportant variable for differentiating the force generating capacity in individuals with STCP from those of their TD peers. On the observation that this parameter responds differently in the two groups is suggestive of the fact that PA may have undergone some degree of transformations in individuals with STCP.

Morphologically, the EO, IO and TrA although appear to be pennated as seen our results, the extent of pennation of these muscle could not be compared to the levels as reported for the limb muscles with a large PA ranging from 18° to 40°. Therefore, to imply that the PA in the abdominal muscles is significant and could be equated to generating muscle force much the same way as the limb muscles would be without adequate scientific and statistically supporting evidence. Additionally, the characterization of
this MAP (change from rest to activity), seems suggestive that PA may not distinguish individuals with STCP from those of TD with regard to force generating capacity and maintenance of stability at the bony pelvis.

CONCLUSION

Our study summarizes that apart from the rectus abdominis muscle, the PA of the oblique and transverse abdominal muscles in individuals with STCP differs from those from TD individuals. The changes in PA between the active and resting stages in both groups seem suggestive that PA as a muscle parameter might have undergone some structural and functional transformations in individuals with STCP. Our study recorded PA of zero degrees for the rectus abdominis muscle in both groups of participants, suggesting that this muscle is non-pennated. The oblique and transverse abdominis muscles on the other hand showed that PA scores were relatively small (less than 3° at their peak), indicative of a weak pennation of the muscle fibers with respect to the lines of pull of these muscles. Further investigation is required on this muscle parameter in order to fully understand its role in the abdominal muscle function with respect to trunk stability.

ACKNOWLEDGMENTS

Special thanks to the staff and learners of all the schools from which participants were recruited for this study. The authors are also grateful to the technical staff of the Division of Anatomy of the Department of Human Biology, Faculty of Health Sciences, University of Cape Town, for transporting the equipment to and from the data sampling sites. Finally, we appreciate the financial inputs of both faculty and management of the postgraduate units of the Faculty of Health Sciences of the University of Cape Town and University of Ghana Medical School toward the doctoral training of the principal investigator.

APPENDIX A.

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PI</td>
<td>AR</td>
<td>Diff</td>
<td>SD Diff</td>
<td>ICC (95% CI)</td>
<td>SEM</td>
</tr>
<tr>
<td>EO R</td>
<td>2.0 ± 0.2</td>
<td>2.2 ± 0.3</td>
<td>−0.2</td>
<td>0.13</td>
<td>0.93 (0.76–0.97)</td>
<td>0.97</td>
</tr>
<tr>
<td>IO R</td>
<td>2.3 ± 0.2</td>
<td>2.2 ± 0.2</td>
<td>−0.1</td>
<td>0.28</td>
<td>0.89 (0.66–0.96)</td>
<td>0.81</td>
</tr>
<tr>
<td>TrA R</td>
<td>1.5 ± 0.5</td>
<td>1.6 ± 0.4</td>
<td>−0.1</td>
<td>0.22</td>
<td>0.85 (0.53–0.94)</td>
<td>0.57</td>
</tr>
<tr>
<td>RA R</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Notes: PI = Measurements of Principal Investigator; AR = Measurements of Assistant Researcher; Diff = difference between PI & AR; SD Diff = standard deviation of the differences; ICC = intra-class confident co-efficient; CI = confident interval; and SEM = standard error of means.
Table A.2 Inter-rater Test for Measurement of Pennation Angle (PA) During Active Stage (Ac) Between PI and AR (STCP; N = 15).

<table>
<thead>
<tr>
<th></th>
<th>PI</th>
<th>AR</th>
<th>Diff</th>
<th>SD Diff</th>
<th>ICC (95% CI)</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>EO Ac (°)</td>
<td>1.8 ± 0.5</td>
<td>2.2 ± 0.2</td>
<td>-0.4</td>
<td>0.18</td>
<td>0.90 (0.78-0.96)</td>
<td>1.10</td>
</tr>
<tr>
<td>IO Ac (°)</td>
<td>2.0 ± 0.3</td>
<td>2.2 ± 0.2</td>
<td>-0.2</td>
<td>0.32</td>
<td>0.91 (0.79-0.96)</td>
<td>0.79</td>
</tr>
<tr>
<td>TrA Ac (°)</td>
<td>1.5 ± 0.5</td>
<td>1.5 ± 0.5</td>
<td>0.0</td>
<td>0.25</td>
<td>0.94 (0.87-0.98)</td>
<td>0.60</td>
</tr>
<tr>
<td>RA R (°)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Notes: PI = Measurements of Principal Investigator; AR = Measurements of Assistant Researcher; Diff = difference between PI & AI; SD Diff = standard deviation of the differences; ICC = intra-class confident co-efficient; CI = confident interval; and SEM = standard error of means.

Table A.3 Inter-rater Test for Measurement of Pennation Angle (PA) During Resting Stage (R) Between PI and AR (TD; N = 15).

<table>
<thead>
<tr>
<th></th>
<th>PI</th>
<th>AR</th>
<th>Diff</th>
<th>SD Diff</th>
<th>ICC (95% CI)</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>EO R (°)</td>
<td>1.6 ± 0.2</td>
<td>1.6 ± 0.2</td>
<td>0.0</td>
<td>0.39</td>
<td>0.95 (0.65-0.99)</td>
<td>0.58</td>
</tr>
<tr>
<td>IO R (°)</td>
<td>2.0 ± 0.2</td>
<td>2.1 ± 0.4</td>
<td>-0.1</td>
<td>0.32</td>
<td>0.93 (0.60-0.97)</td>
<td>0.62</td>
</tr>
<tr>
<td>TrA R (°)</td>
<td>1.4 ± 0.2</td>
<td>1.5 ± 0.2</td>
<td>-0.1</td>
<td>0.43</td>
<td>0.92 (0.80-0.94)</td>
<td>0.61</td>
</tr>
<tr>
<td>RA R (°)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Notes: PI = Measurements of Principal Investigator; AR = Measurements of Assistant Researcher; Diff = difference between PI & AI; SD Diff = standard deviation of the differences; ICC = intra-class confident co-efficient; CI = confident interval; and SEM = standard error of means.

Table A.4 Inter-rater Test for Measurement Pennation Angle (PA) During Active Stage (Ac) Between PI and AR (TD; N = 15).

<table>
<thead>
<tr>
<th></th>
<th>PI</th>
<th>AR</th>
<th>Diff</th>
<th>SD Diff</th>
<th>ICC (95% CI)</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>EO Ac (°)</td>
<td>1.8 ± 0.2</td>
<td>1.8 ± 0.2</td>
<td>0.0</td>
<td>0.35</td>
<td>0.94 (0.58-0.98)</td>
<td>0.53</td>
</tr>
<tr>
<td>IO Ac (°)</td>
<td>2.2 ± 0.2</td>
<td>2.3 ± 0.3</td>
<td>-0.1</td>
<td>0.44</td>
<td>0.96 (0.52-0.96)</td>
<td>0.60</td>
</tr>
<tr>
<td>TrA Ac (°)</td>
<td>1.5 ± 0.3</td>
<td>1.6 ± 0.2</td>
<td>-0.1</td>
<td>0.38</td>
<td>0.95 (0.65-0.99)</td>
<td>0.65</td>
</tr>
<tr>
<td>RA Ac (°)</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Notes: PI = Measurements of Principal Investigator; AR = Measurements of Assistant Researcher; Diff = difference between PI & AI; SD Diff = standard deviation of the differences; ICC = intra-class confident co-efficient; CI = confident interval; and SEM = standard error of means.

References


